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Performance and Exhaust Emission Studies of an Adiabatic Engine with Optimum Cooling

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Abstract

An attempt has been made to study the performance and exhaust emission studies of a diesel engine by insulating the combustion chamber using ceramic material attaining an adiabatic condition. The cycle average gas temperature and metal surface temperature are higher in adiabatic engine. Many researchers have carried out a large number of studies on LHRE (Low Heat Rejection Engine) concept.[7] In the case of LHR engines almost all theoretical studies predict improved performance but many experimental studies show different picture. An experimental investigation of the performance of a ceramic coated engine was carried out and the results were compared to the base engine. Piston top surface, cylinder head and liners of a multi cylinder vertical water cooled self-governed diesel engine were fully coated with Partially Stabilized Zirconia (PSZ).The engine was run at an optimum water cooling condition with constant speed and variable load condition as observed in most urban driving conditions. During the experiment, various measurements like fuel flow, exhaust temperature, exhaust emission were carried out. The results indicate improved fuel economy and reduced pollution levels for the Thermal Barrier Coated (TBC) engine.

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Keywords: TBC diesel engine; Partially Stabilized Zirconia; LHRE engine; Thermal efficiency; Mechanical efficiency; Volumetric efficiency; Exhaust emission; Smoke density; Heat balance sheet.

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1. Introduction of TBC

Heat engines are designed and manufactured considering various factors such as durability, performance and efficiency with the objective of minimum life cycle cost. The performance of internal combustion engines needs to be improved depending on some technological requirements and rapid increase in the fuel expenses. On the other hand, the improvements in the engine materials are forced by using alternate fuels and environmental requirements. Therefore, the choices of engine material become very important. Metallic coatings were introduced to sustain high temperatures. The trend for the most efficient internal combustion is to exploit more advances in material and cooling technology by going to engine operating cycles which employ a large fraction of the maximum temperature capability for the entire operating cycle.[1,2] Thermal Barrier Coatings (TBC) performs the important function of insulating components of I.C. Engine, gas turbine and aero engine operating at elevated temperatures. Thermal barrier coatings (TBC) are layer systems deposited on thermally high loaded metallic components, as for instance in engine. TBC's are characterized by their low thermal conductivity. The coating when exposed to heat bears a large temperature gradient. The most commonly used TBC material is Yttrium Stabilized Zirconia (YSZ), which exhibits resistance to thermal shock and thermal fatigue up to 1150^{o}C. YSZ is generally deposited by plasma spraying and electron beam physical vapour deposition (EBPVD) processes. It can also be deposited by high velocity oxy fuel (HVOF) spraying for applications as wear prevention, where the wear resistant properties of this material can also be used. The use of the TBC raises the process temperature and thus increases the efficiency.[5,6]

Thin ceramic coating of 500 microns was applied on the top surface of the pistons with bowls, head of the cylinder, liners and valves of the diesel engine. To avoid overheating & under cooling of engine, optimum cooling water mass flow rate was obtain which gives maximum overall efficiency of the engine for different load condition of engine.[4,10]The aim was to investigate the performance of diesel engine under said thermal barrier coated components with optimum cooling water conditions ,effect on heat balance sheet, exhaust emissions and smoke density.[8,9]

The thermal barrier coating of zirconium $Zr\,O_2$ is selected because of its better wear resistance , low thermal conductivity , high thermal shock resistance & high melting point (about 2800^{0}C). The bond coat of nickel aluminium powder provides good corrosion proactive bond coats and by forming a protective oxide scale. Use of composite ceramic powder coating results into excellent flow ability, chemical homogeneity, structural stability, uniform particle melting etc. Use of plasma spray coating in TBC results into production of high temperature, resistance to thermal cycling stresses and strains.[3] Plasma spray process parameters for zirconium oxide $Zr\,O_2$ are:

1.	Material specification	: -22 ± 5 Microns
2.	Stabilizer agents Bond coat	: NiAl (Ni-95%, Al-5%)
3.	Coating thickness	: 500 Microns
4.	Power required	: 32.5 KW.
5.	Voltage	: 65 V
6.	D. C. Current	: 500Amp.
7.	Plasma generating gas	: Argon (Ar)
8.	Powder deposition distance	: 70 to 90 mm.
9.	Powder feed rate	: 20-25 Grams / min.
10.	Pressures	: 120 Psi.
11.	Plasma process type	: D. C. Arc

2. Experimental set up

The experimental work was carried out on twin cylinder four stroke vertical water cooled diesel engine with a bore of 80 mm and stroke 110 mm. The engine is rated for 7.35 (10 HP) and 1500 RPM with a centrifugal governor to control the speed. The engine was connected with a electric dynamometer was used to measure the power output. The engine is instrumented to measure the parameters like fuel consumption, load ,speed of engine, cooling water temperature, inlet air and exhaust gas temperature etc. The engine test was carried out with constant speed of 1500 RPM and load was varied from no load to the maximum load conditions. For different load conditions engine performance parameters were checked on base engine and ceramic coated engine. The following tests were carried out: Performance test, Heat balance test and smoke test. During the experiment due care was taken to maintain optimum mass flow rate of cooling water for each load on engine for avoiding overheating and under cooling of diesel engine.

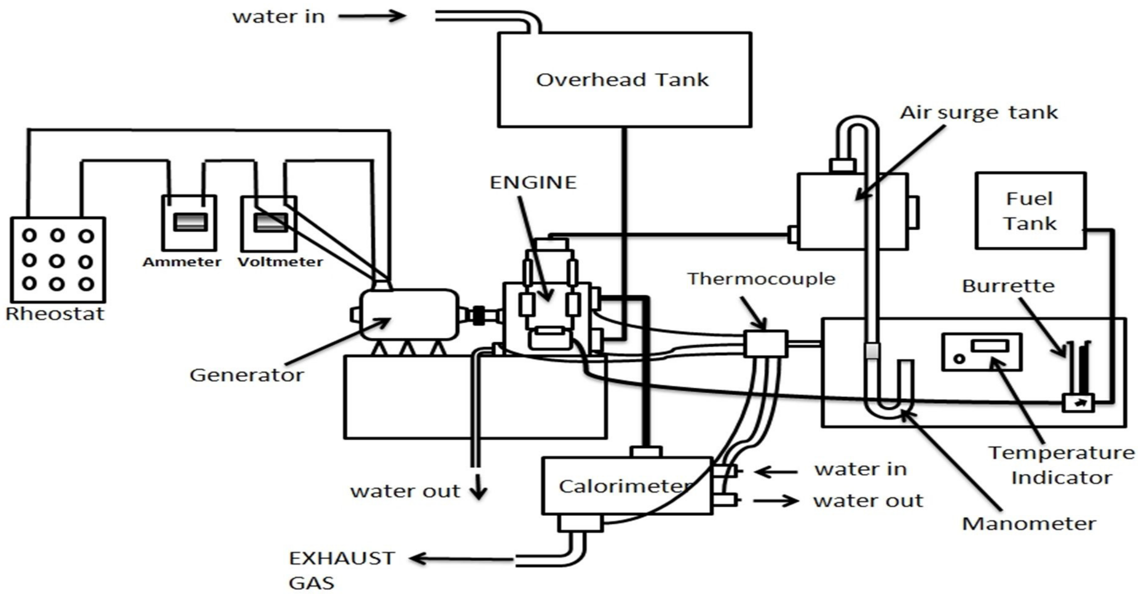


Fig.1. Experimental Setup

3. Results & Discussions

3.1 Specific Fuel Consumption (SFC)

It is found in case of adiabatic engine for almost all load conditions, the SFC is little less than that of the base engine and after full load the SFC is less up to 20.70 gm/kwHr (8%). This may be due to higher operating temperature which in turn improves combustion characteristics.

3.2 Break Thermal Efficiency (BTE)

With the use of TBC engine it is seen that initially brake thermal efficiency is little less at low load condition with reference to base load engine. At full load conditions brake thermal efficiency is 2.85% more in case of TBC engine which represents brake thermal efficiency gets improved by 8.48 %. This may be due to reduced loss of heat to coolant and greater availability of heat in combustion chamber of the engine.

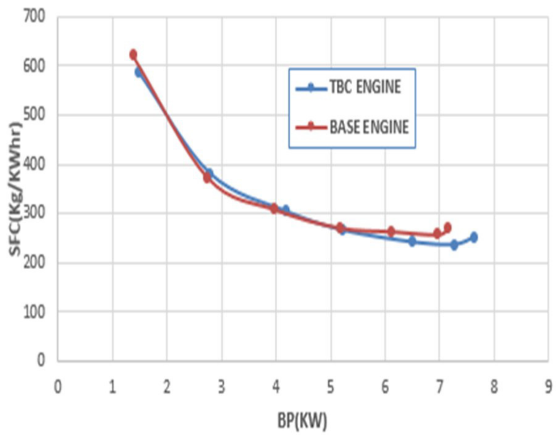


Fig. 2. Comparisons of BP v/s SFC

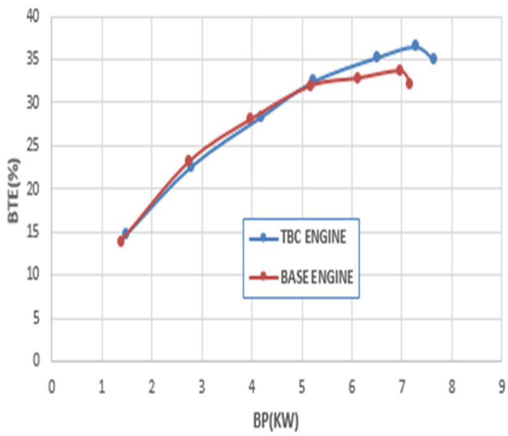


Fig. 3. Comparisons of BP vs BTE

3.3 Indicated Thermal Efficiency (ITE)

It can be observed from the graph that indicated thermal efficiency of TBC coated engine is 3.78 % higher compared to base engine (which indicates ITE improvement up to 7.87%). ITE is higher at higher load condition in case of adiabatic engine. This may be due to minimise heat loss & gives better combustion efficiency.

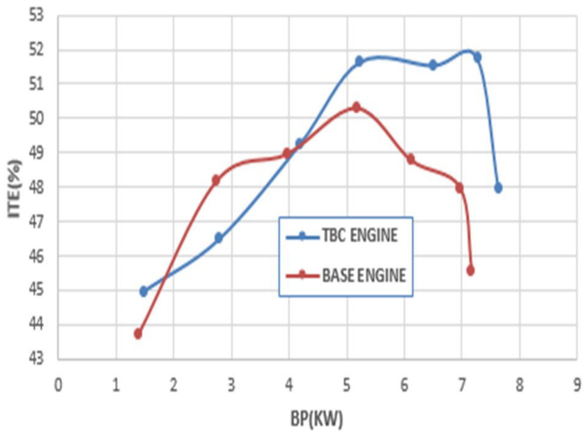


Fig. 4. Comparisons of BP vs ITE

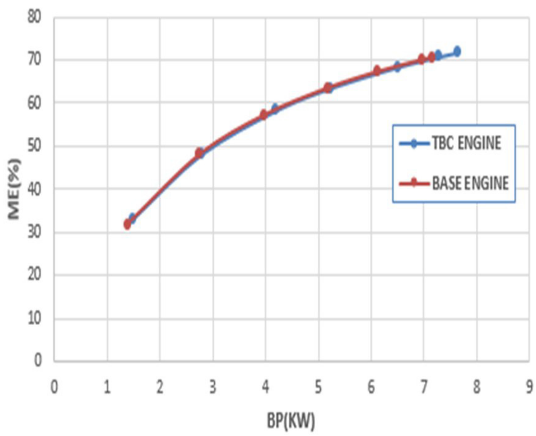


Fig.5. Comparisons of BP v/s ME

3.4 Mechanical Efficiency (ME)

It can be seen from the graphs that mostly at all load conditions mechanical efficiency of adiabatic engine is 1 % higher compared to standard base engine. This may be due to reduction in heat loss because of components being thermal coated. This may be due to minimise the friction in combustion chamber at higher operating temperature of lubricant oil.

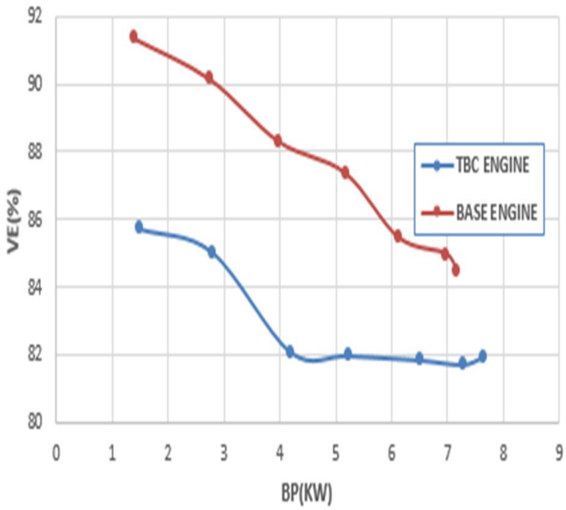


Fig. 6. Comparisons of BP v/s volumetric efficiency

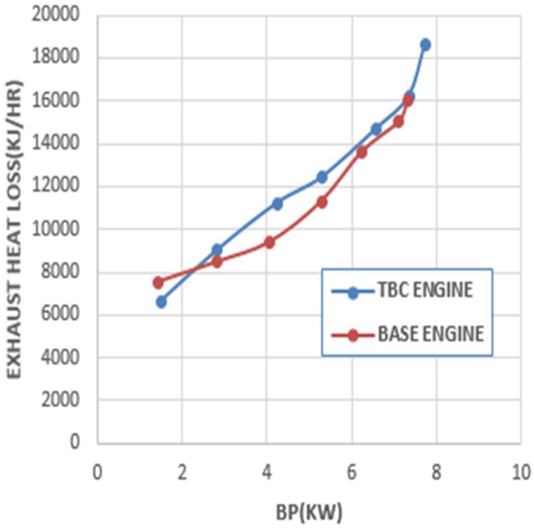


Fig. 7. BP v/s Heat loss in exhaust gas (Average)

3.5 Volumetric Efficiency (VE)

It is found that the volumetric efficiency of coated engine is 3.0 % to 7.0 % less than the base engine. This may be due to higher operating temperature of coated engine. Which increase the piston speed & as a result less air was sucked in combustion chamber. This can be overcome by providing turbocharger.

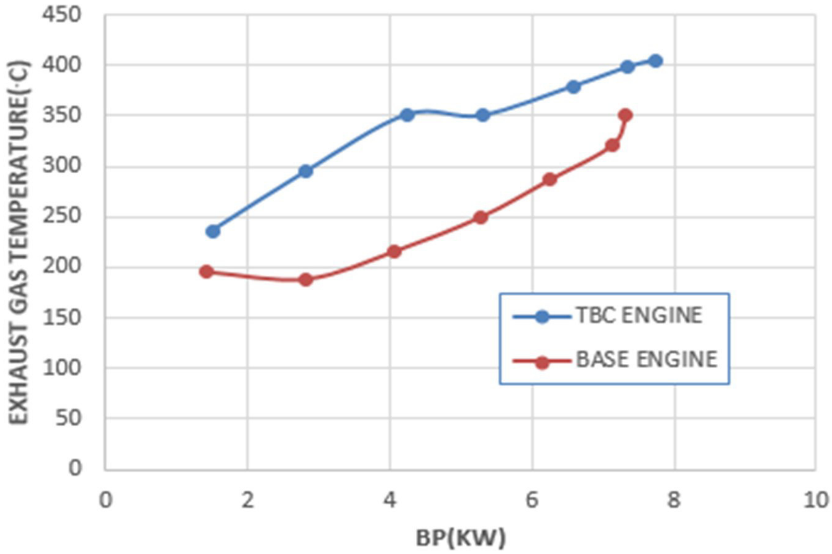


Fig. 8. BP v/s Heat loss in exhaust gas temperature

3.6 Exhaust heat loss & Exhaust gas temperature

It is found that the heat in exhaust for an adiabatic engine is 16.56% more than that of the standard engine. Due to higher gas temperature of the cycle and surface temperature of combustion chamber, temperature of exhaust gas increases due to higher amount of heat in. By adopting the turbocharger or ranking bottoming cycle or with the help of suitably designed heat exchanger the heat lost to exhaust can be successfully recovered and supplied back to the engine.

It is found from the graph that exhaust gas temperature of an adiabatic engine is almost higher (about 1^0 C to 55^0C) than the base engine.

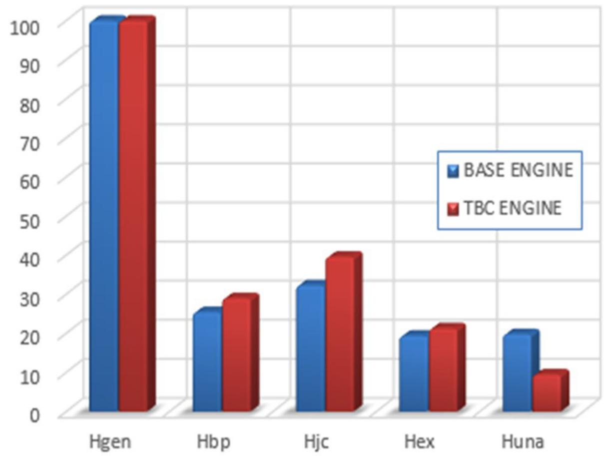


Fig. 9: Heat Balance Sheet (Average)

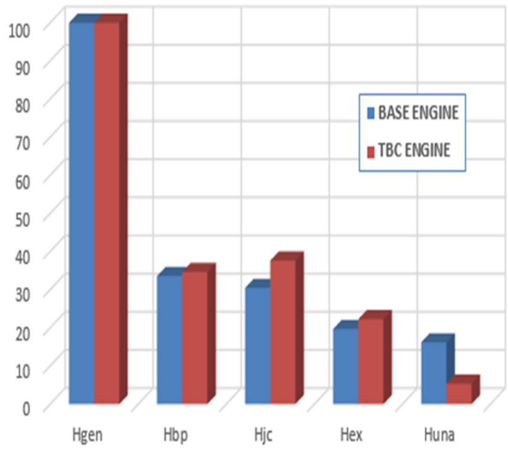
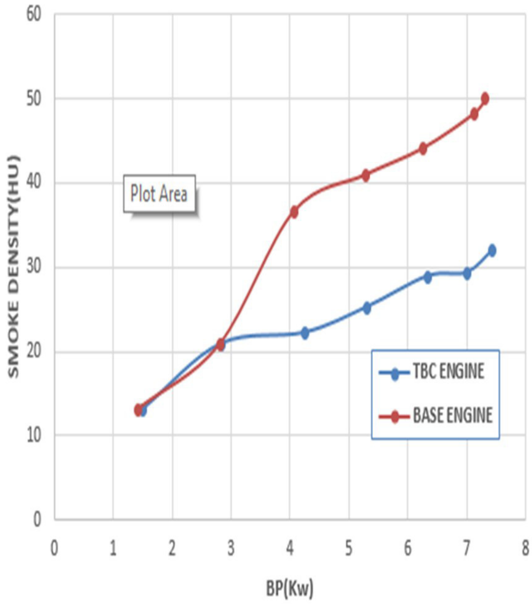


Fig. 10. Heat Balance Sheet (At rated power)

3.7 Heat Balance Sheet

It is found that heat used in producing brake power gets improved by about 14% due to thermal barrier coating. It can be seen that approx. 22.6% more heat goes with coolant as compared to base engine. This may be due to higher operating temperature of coated engine and reduced radiation losses. Heat lost by radiation and unaccounted losses gets reduced by 52%. This may be due to thermal barrier coated components which reduces the heat loss from the combustion chamber.



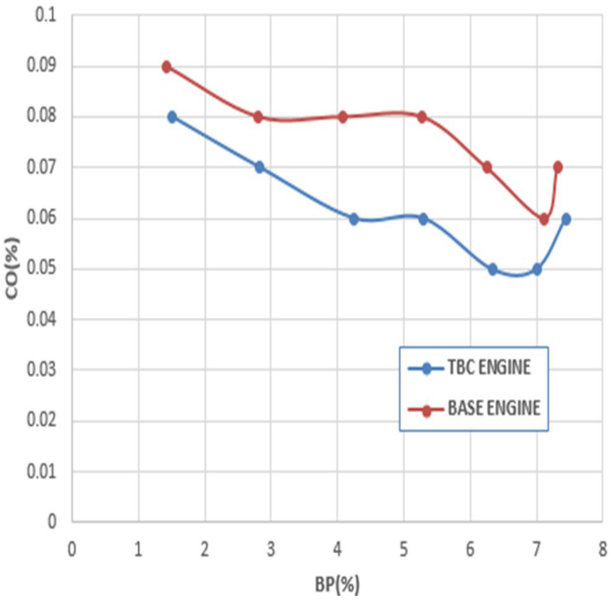


Fig.11. BP v/s Smoke Density

Fig. 12. BP v/s CO

3.8 *Smoke Density*

From the graph of Brake Power Vs Smoke for zirconium coated engine and base engine it is observed that the smoke level increase with increase in load at all load conditions. At all load conditions there is reduction in smoke level due to zirconium coating. At full load condition smoke density level gets decreased by approx. 39%.

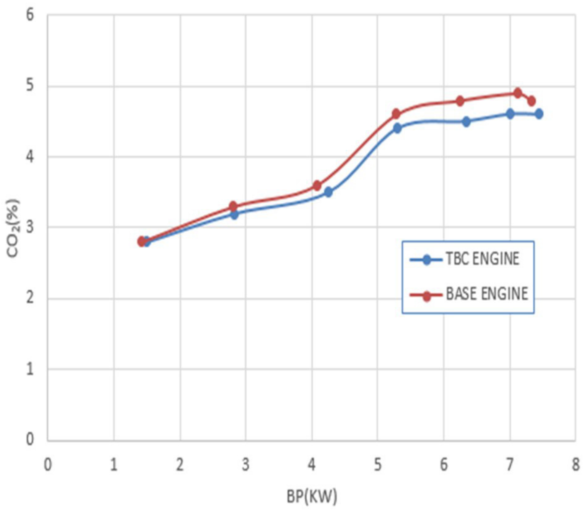


Fig. 13. BP v/s CO_2

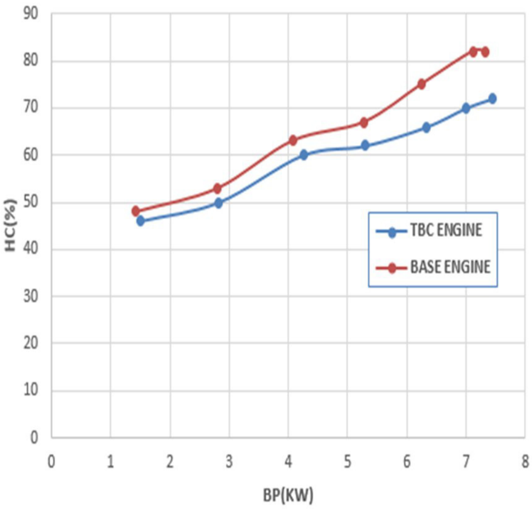


Fig.14. BP v/s HC

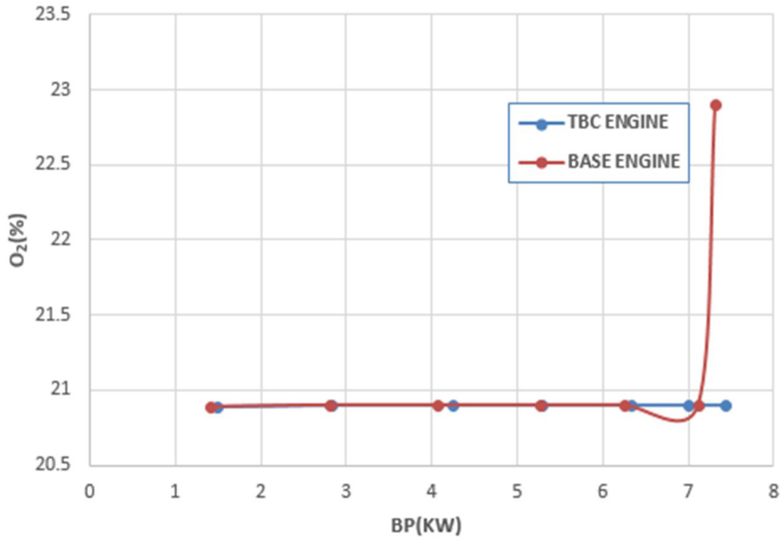


Fig. 15. BP v/s O_2

3.9 Emission Test

From the graphs of BP Vs HC, BP Vs CO, BP Vs CO2, BP Vs O2 it can be inferred that all emission increase with increase in load and becomes maximum at full load conditions for both the cases. Level of HC / CO/CO2 in exhaust gases gets reduced in case of TBC engine when compared to base engine. Reduced HC and CO indicates better combustion due to thermal barrier coating. HC consist of small non equilibrium molecular which are formed when large fuel molecular breakup (thermal cracking) during combustion reaction No significant change is observed in O2 level present in exhaust gases in case of TBC engine compared to base engine.

4. Conclusion

The following conclusions are made based on the experimental results.

1) The general performance of the adiabatic engine is found to be better than that of base engines. The SFC was 5-8% lower than that of base engine.
2) The mechanical efficiency of adiabatic engine is found to be 1% higher than that of the base engine, and an overall increase of 10% in brake thermal efficiency was observed.
3) The volumetric efficiency of adiabatic engine is 3.0 % to 7.0 % less than the base engine.
4) The smoke emission from the adiabatic engine was 39% lower than that in the base engine.
5) The emissions of Carbon monoxide (CO), Carbon dioxide (CO_2) ,Hydrocarbon (HC) and Oxygen level O2 is almost lower in adiabatic engine compared to base engine.
6) The heat balance sheet indicates that some amount of heat wasted in the base engine, is utilized to increase the brake power in the adiabatic engine and some amount of heat is lost in exhaust gas.
7) The radiation and other unaccountable losses were also reduced by 52% than that in the base engine.

5. Scope for Future Work

- The increased energy in the exhaust has to be recovered suitably in order to boost the overall thermal efficiency. The higher heat content of the exhaust indicates the availability of considerable energy which can be used to operate a low pressure turbine. The other method of recovering this energy would be the organic Rankine Bottoming Cycle. An overall efficiency of about 50% has been predicted for such combinations.

- The higher frictional losses are due to deterioration in properties of the lubricating oil resulting from the higher temperature of the combustion chamber surface. Hence, one of the main directions of the research in adiabatic engine should be the development of lubricating oil capable of retaining satisfactory viscosity at the higher temperature encountered in the engine.
- In order to obtain better performance over a wide range of engine load, it becomes necessary to use the engine with a turbocharger.
- Due to the higher operating temperature of an adiabatic engine, low grade fuels such as alcohol, esterified castor oil, esterified neem oil, kerosene and fuel with low cetane number can also be used.

References

[1] Juji Suzuki, Tadashi Suzuki, Takaaki kawakawa, Akihiko Suda, Hideo Sobukawa, Masahiro Sugiura. Development of Three-Way Catalyst Using Composite Aluminia-ceria-Zircinia, SAE paper 2003-01-0811, March 2003.
[2] Jaichandar S, Tamilporai P. Low Heat Rejection Engine – An Overview, SAE paper 2003-01-0405, March 2003
[3] Udaykumar R. Development and testing of a low heat rejection engine ,I C engine and combustion ,Editor P. K. bose, Narosa publication house New Delhi ,India.
[4] Seeniraj R.V, Arunacham M, venkatachalapatny R, Premkumar C. Some basic heat transfer studies in ceramic coated I C engine components and the performance test on a ceramic coated diesel engine, Elegant national conference on I C Engine, MED, IIT Madras,11-15,1989.
[5] Baluswamy N, selvakumar P. Experimental investigation of the performance of adiabatic diesel engines, Elegant national conference on I C Engine, MED , IIT Madras,11-15,1989.
[6] Yadav R. Internal combustion engines and air pollution, M N R E C Allahabad,
[7] Sudhir Sen, Ceramic whitewares their technology & application Publication by offord & IBH co. pvt. Ltd.
[8] Heywood JB. Internal Combustion Engine Fundamentals, Mcgraw Hill International Edition, 2002.
[9] Eugene L. Keating. Applied Combustion Second Edition, CRC Press Taylor & Francis Group, Newyork, 2007
[10] Mewes D, Mayinger F. Heat and Mass Transfer, Prof. Dr. Ing. Dieter Mewes. Universitat Hannover, Institute fur Verfahrenstechnik Callinstr. 36, 30167, Hannover, Germany.